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(54) **METHOD FOR RAPID CHARGE CONTROL IN LITHIUM BATTERIES**

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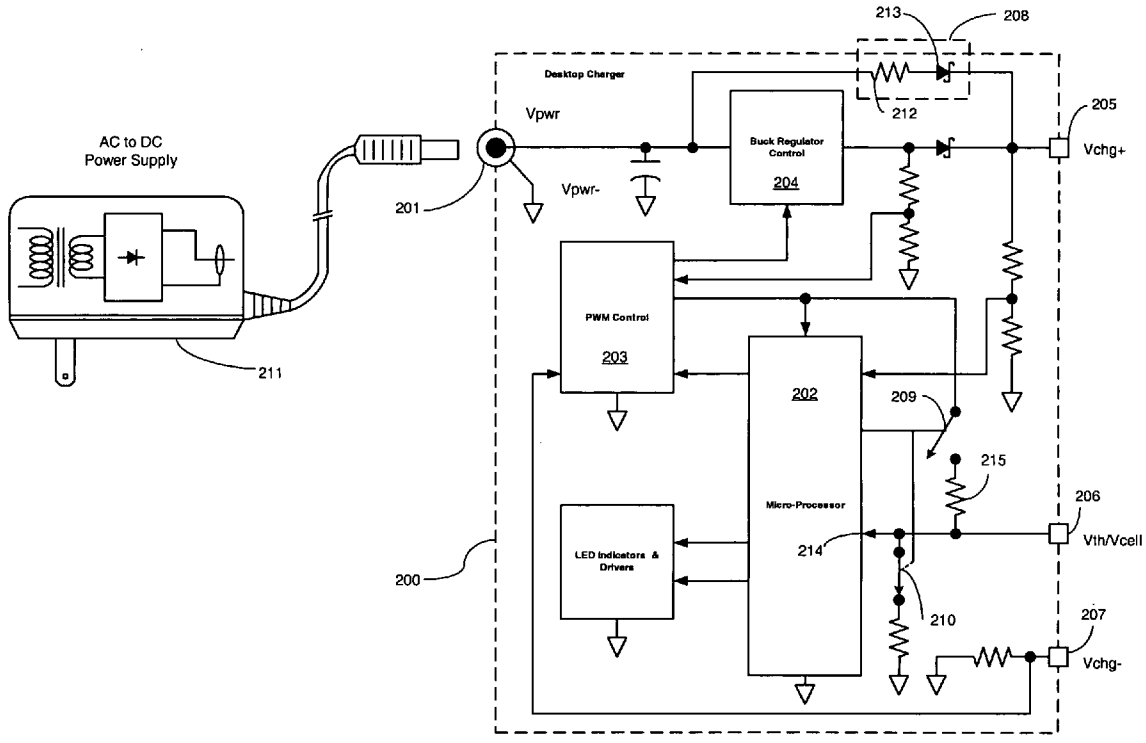
(57) **ABSTRACT**

This invention includes a method for charging lithium-based batteries. Battery type is identified by a charger by way of a third terminal. For nickel-based cells, the third terminal is coupled to a thermistor for sensing temperature. For lithium-based cells, the third terminal is coupled to the rechargeable cell disposed within the battery pack. If a nickel cell is identified, the cell is charged by conventional means. If a lithium cell is identified, the charger applies a full current until any serial elements disposed between the battery pack terminals and the cell reach a high impedance state. The charger then reduces the charging current to a low level for a predetermined time. After this time has elapsed, the charger then reapplies a high current. If the voltage across the serial elements remains low, charging continues. However, if the voltage across the serial elements exceeds a predetermined threshold, the charger then decrements the current by a predetermined amount.



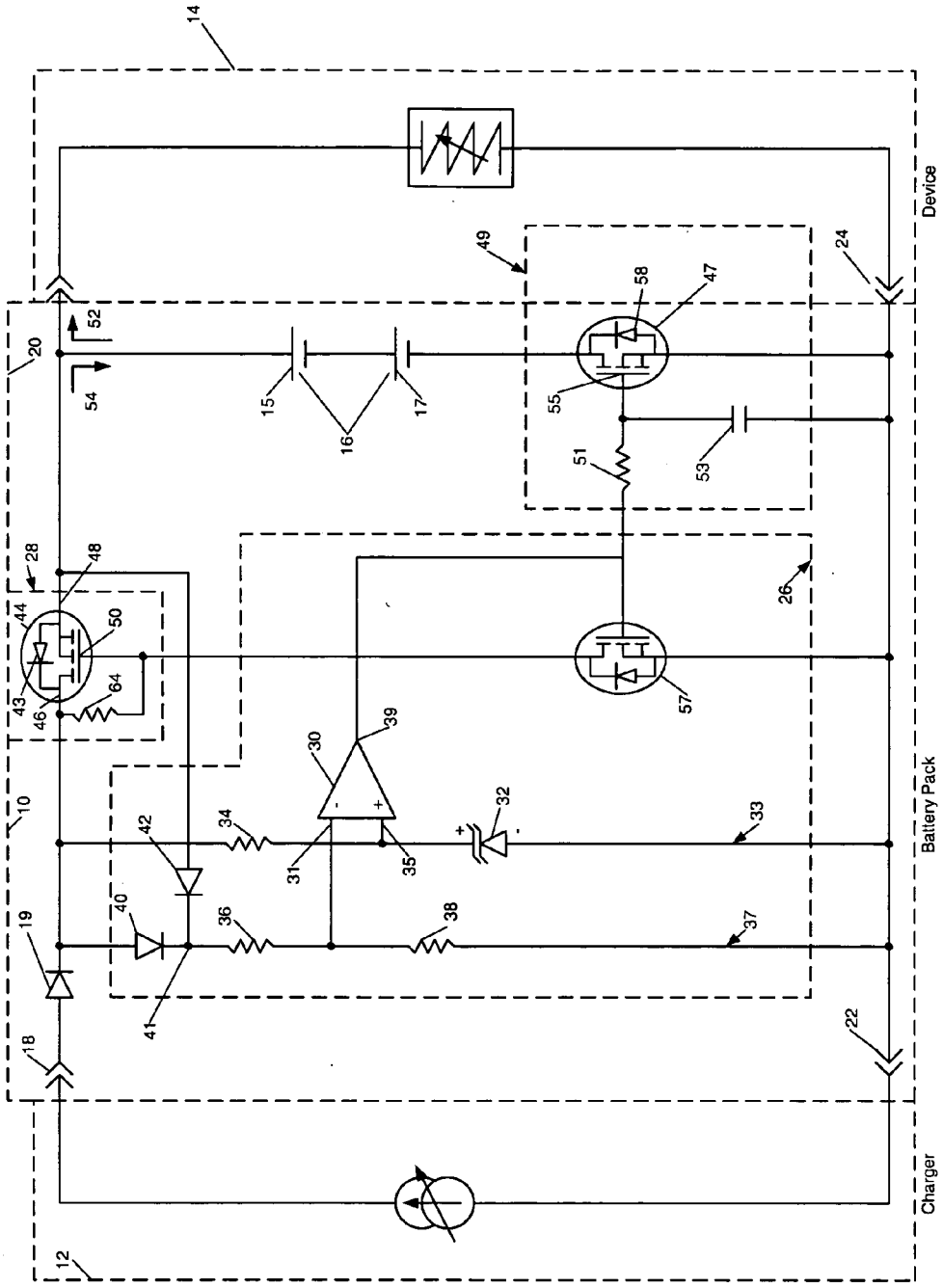


FIG. 1
(Prior Art)

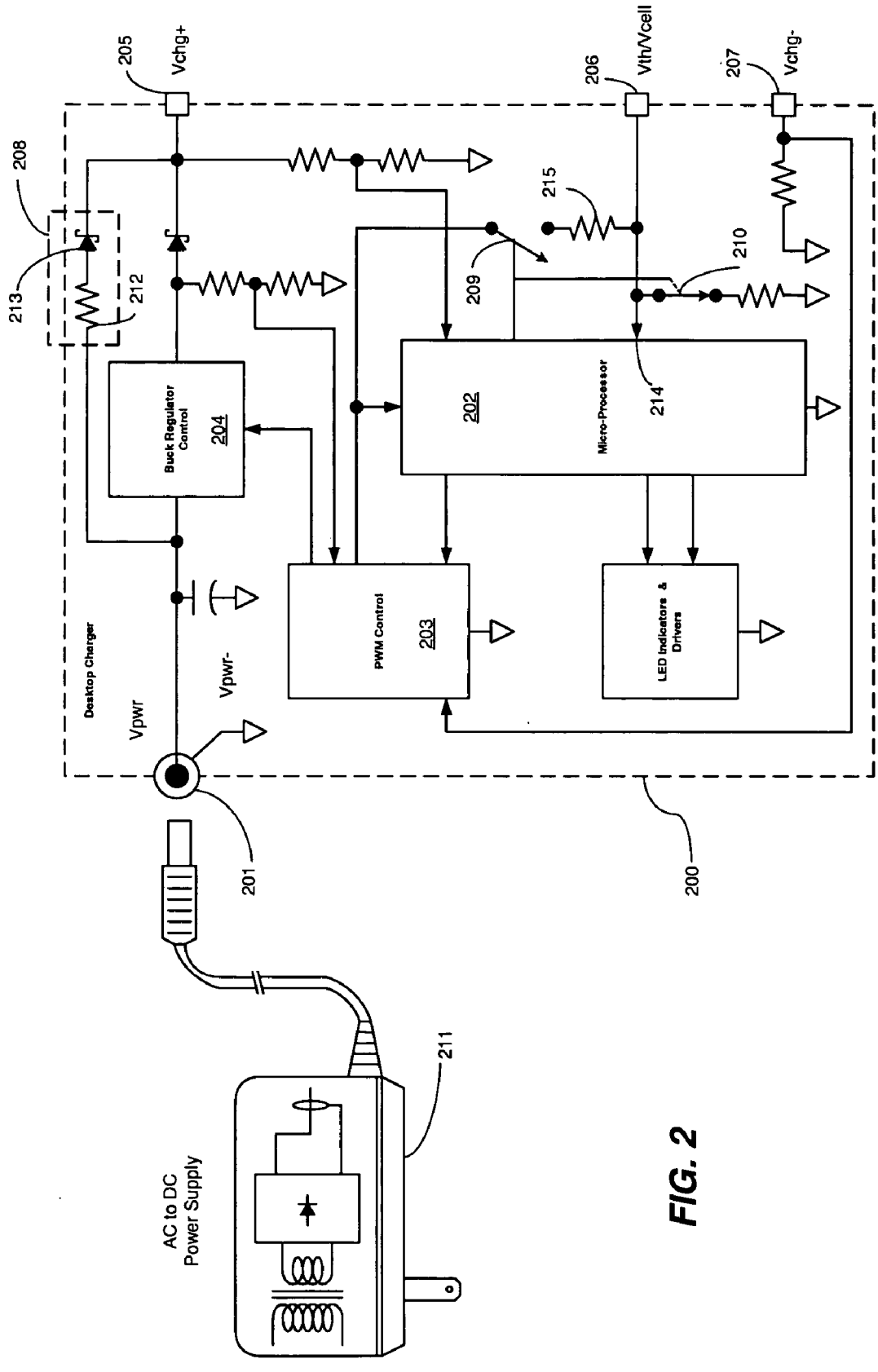

205
Vchg+
206
Vth/Vcell
207
Vchg-
208
213
212
215
209
210
214
Buck Regulator Control
204
202
Micro-Processor
PWM Control
203
LED Indicators & Drivers
Desktop Charger
Vpwr
Vpwr-
201
200
211
AC to DC
Power Supply

FIG. 2

FIG. 3

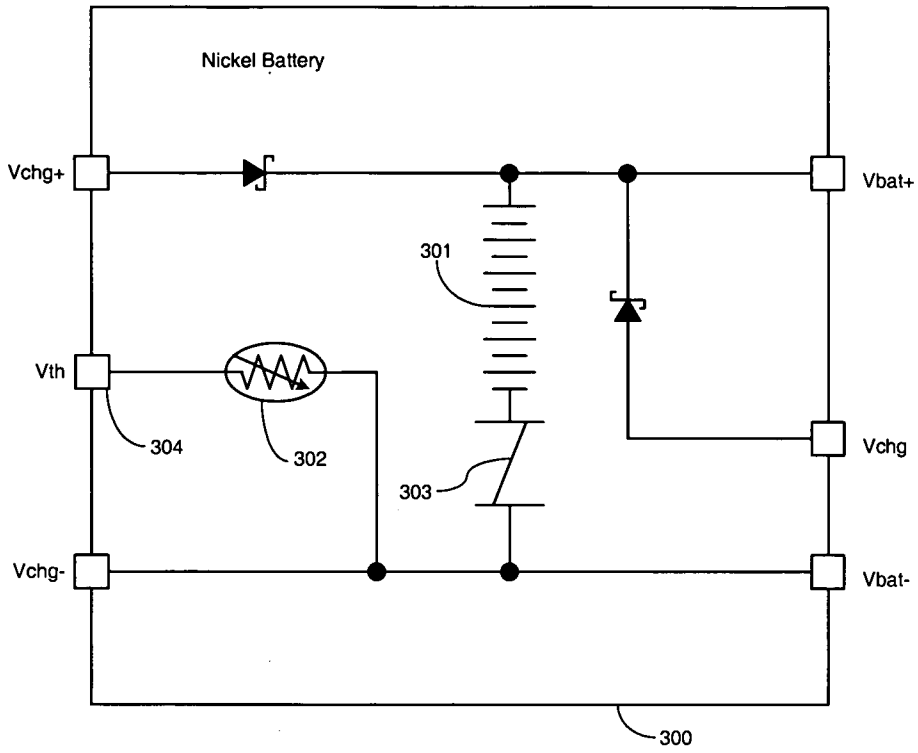
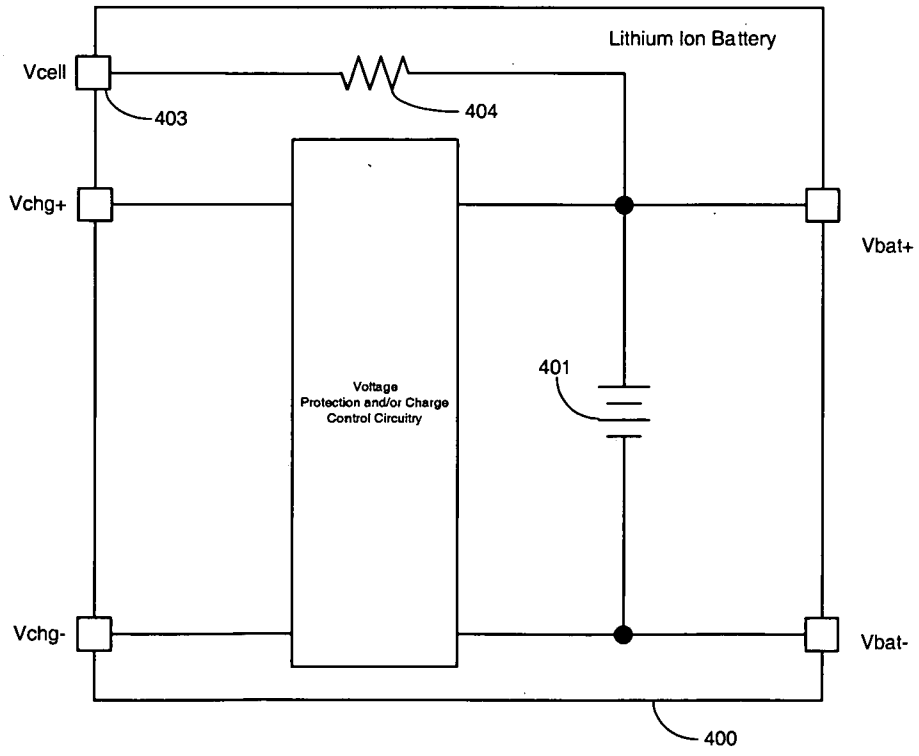

Nickel Battery
Vchg+
Vbat+
301
Vth
304
302
303
Vchg
Vchg-
Vbat-
300

FIG. 4


Lithium Ion Battery
Vcell
403
404
Vchg+
Vbat+
Voltage
Protection and/or Charge
Control Circuitry
401
Vchg-
Vbat-
400

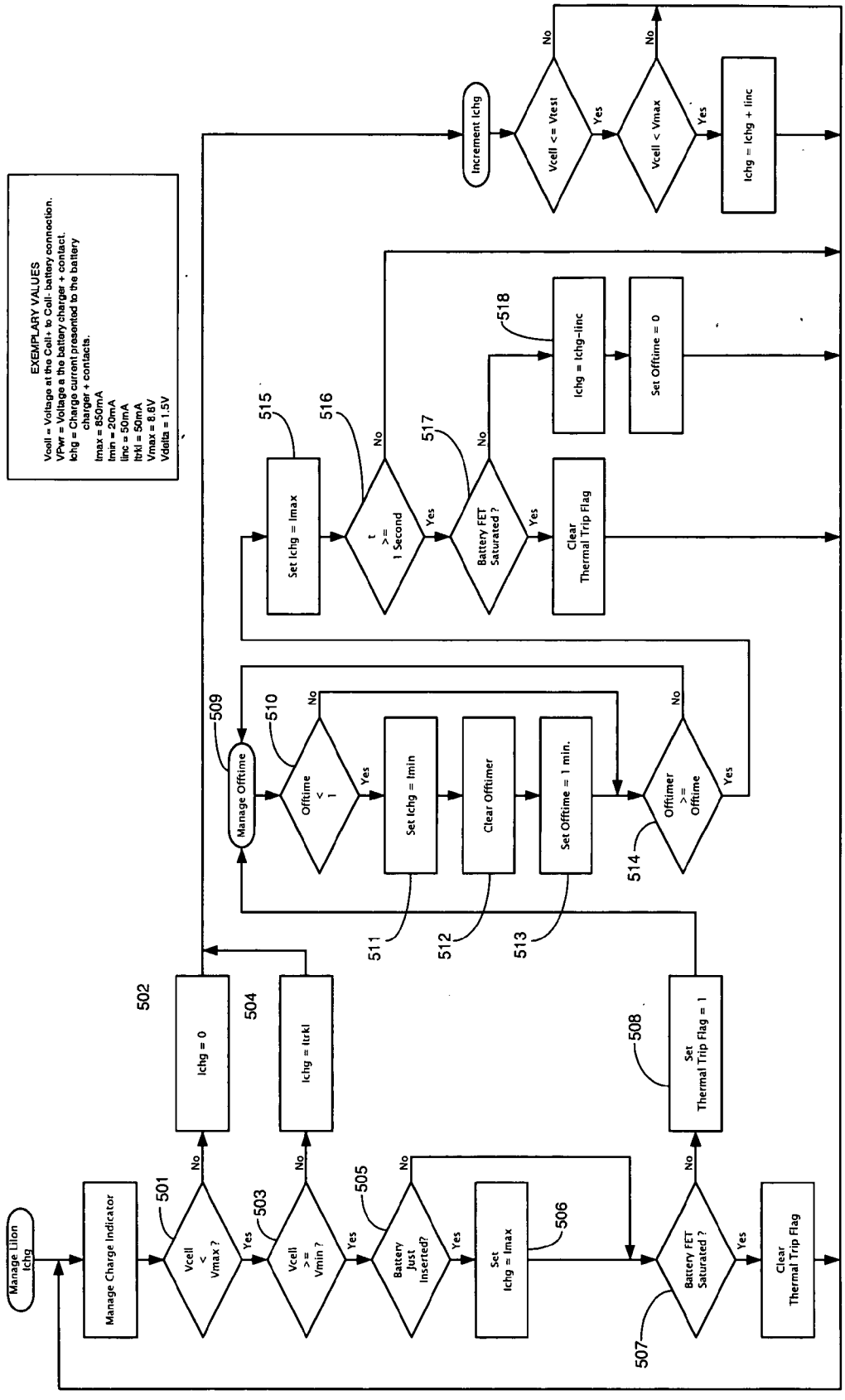

Manage LiIon Ichg
Manage Charge Indicator
501
Vcell < Vmax ?
No
Yes
502
Ichg = 0
503
Vcell >= Vmin ?
No
Yes
504
Ichg = Itrkl
505
Battery Just Inserted?
No
Yes
506
Set Ichg = Imax
507
Battery FET Saturated ?
No
Yes
508
Set Thermal Trip Flag = 1
Clear Thermal Trip Flag
509
Manage Offtime
510
Offtime < 1
No
Yes
511
Set Ichg = Imin
512
Clear Offtimer
513
Set Offtime = 1 min.
514
Offtimer >= Offtime
No
Yes
515
Set Ichg = Imax
516
t >= 1 Second
No
Yes
517
Battery FET Saturated ?
No
Yes
518
Ichg = Ichg-Iinc
Set Offtime = 0
Clear Thermal Trip Flag
Increment Ichg
Vcell <= Vtest
No
Yes
Vcell < Vmax
No
Yes
Ichg = Ichg + Iinc
EXEMPLARY VALUES
Vcell = Voltage at the Cell+ to Cell- battery connection.
VPwr = Voltage a the battery charger + contact.
Ichg = Charge current presented to the battery charger + contacts.
Imax = 850mA
Imin = 20mA
Iinc = 50mA
Itrkl = 50mA
Vmax = 8.6V
Vdelta = 1.5V

FIG. 5

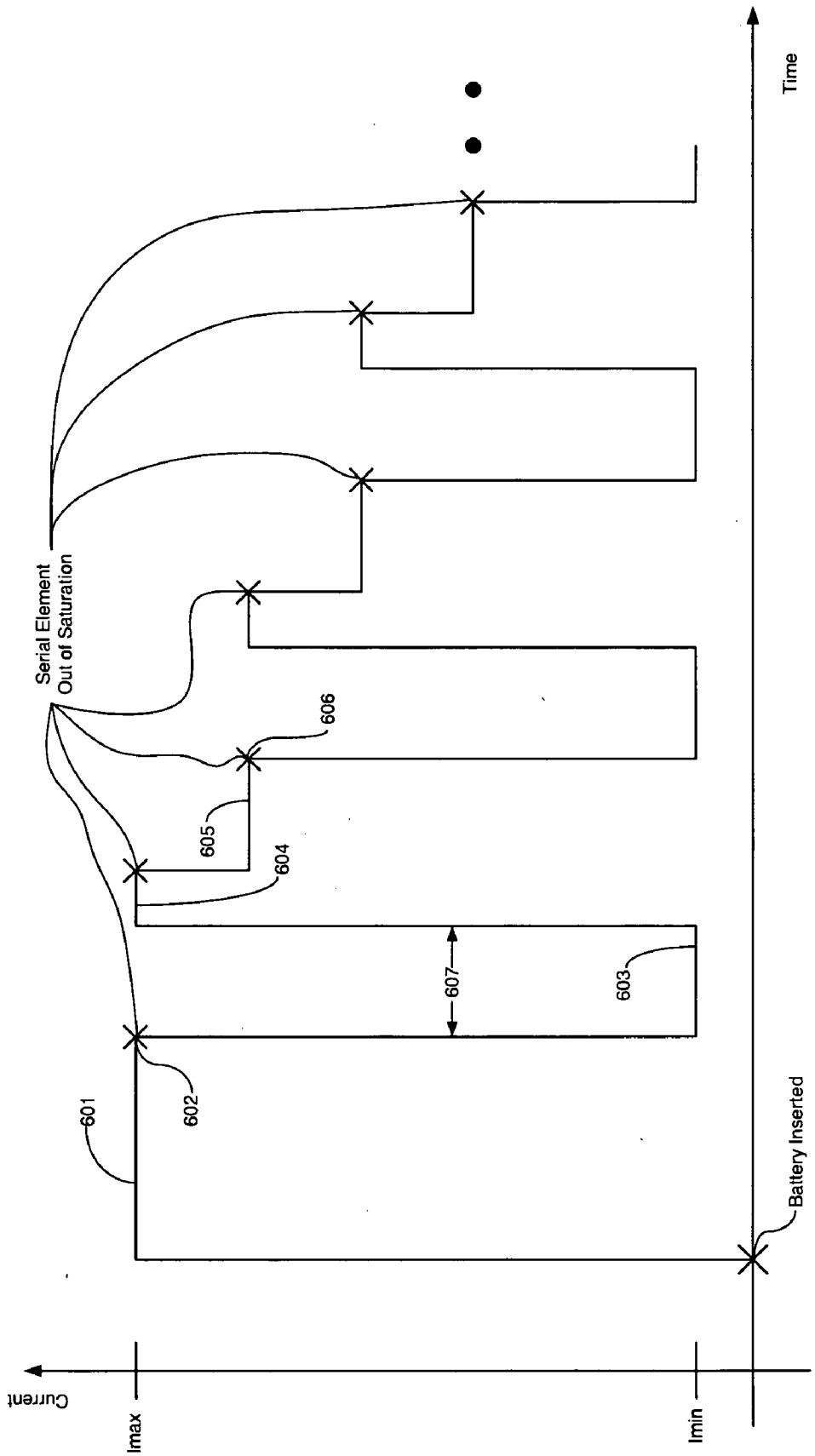

Time
Serial Element Out of Saturation
606
605
604
607
603
602
601
Battery Inserted
Current
Imax
Imin

FIG. 6

METHOD FOR RAPID CHARGE CONTROL IN LITHIUM BATTERIES

BACKGROUND

[0001] 1. Technical Field

[0002] This invention relates generally to chargers for rechargeable battery cells, and more specifically to chargers capable of identifying different battery cell chemistry types and charging the cells accordingly.

[0003] 2. Background Art

[0004] The portable electronic devices of today rely upon rechargeable batteries for portability. Modern cellular phones, pagers, radios, compact disc players, MP3 players, laptop computers and the like all use rechargeable batteries. These rechargeable batteries are manufactured in many different chemistries, including Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH) and lithium based chemistries. Nickel based batteries offer higher peak currents, whereas lithium based batteries are generally lighter with higher energy densities.

[0005] Nickel and lithium based batteries must be charged differently due to their different chemical compositions. For example, battery chargers terminate the nickel charging cycle by measuring a change in temperature across time. Chargers terminate the lithium charging cycle, contrastingly, by simply measuring voltage. As both nickel and lithium are suitable for some applications, like cellular phones or radios, a charger must be able to identify between the two chemistries to charge the cells properly.

[0006] One prior art method of identifying battery chemistry is by way of a coding resistor. Such a resistor is taught in U.S. Pat. No. 4,006,396, entitled "Universal Battery Charging Apparatus", issued to Bogut, which is incorporated herein by reference for all purposes. In this method, different battery types are equipped with resistors having different resistance values. The charger senses the value resistor In the battery and determines the battery type by comparing the sensed resistance to resistances and associated battery types stored in a look-up table read from the charger's memory.

[0007] While this method of identification lets the charger know what type of cell is being charged, it does not tell the charger what type of circuitry is in the battery alongside the cell. While older batteries may have comprised a cell and a box, modern batteries include all types of electronic circuitry, including charging protection circuits, fuel gauging circuits, and microprocessors. One such battery **10** is shown in **FIG. 1**. This battery **10** is taught U.S. Pat. No. 5,539,299, entitled "Protection switch for a battery powered device", issued to Fernandez et al, incorporated herein by reference for all purposes.

[0008] As can be seen by looking at the battery **10**, multiple elements, including a diode **19** and charging protection pass element **28**, are coupled in series with the cells **16**. If the cells **16** are lithium, and if the charger **12** tries to sense voltage (for charge termination) at the terminals **18,22**, the voltage sensed will be inaccurate due to the voltages across the serial components **19,28**. Further, some battery circuits—like that recited in copending application Ser. No. 10/185,095, filed Jun. 29, 2002, entitled "Thermally Limited Battery Protection and Charging Circuit", incorporated herein by reference for all purposes—include pass elements that are thermally triggered. If a thermal event triggers opening of the pass element, any voltage measurement at the battery terminals will be invalid.

[0009] There is thus a need for a charger with an improved identification means and charging termination method for lithium cells that is capable of properly terminating charge despite circuit elements that may be coupled serially with the cell.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] **FIG. 1** illustrates a prior art battery circuit.

[0011] **FIG. 2** illustrates the block diagram schematic of a charger in accordance with the invention.

[0012] **FIG. 3** illustrates a nickel-based battery in accordance with the invention.

[0013] **FIG. 4** illustrates a lithium-based battery in accordance with the invention.

[0014] **FIG. 5** illustrates a method of charging lithium-based batteries in accordance with the invention.

[0015] **FIG. 6** is a graphical illustration of an exemplary charging current for lithium-based batteries in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0016] A preferred embodiment of the invention is now described in detail. Referring to the drawings, like numbers indicate like parts throughout the views. As used in the description herein and throughout the claims, the following terms take the meanings explicitly associated herein, unless the context clearly dictates otherwise: the meaning of "a,""an," and "the" includes plural reference, the meaning of "in" includes "in" and "on."

[0017] This invention provides a charger with a circuit capable of identifying the type of cell to be charged. The charger then selects a charging termination method based upon the cell identification. Nickel based cells terminate charge as is known in the art, preferably by a change in temperature of the cell per change in time. The invention terminates charge in lithium cells in a novel manner that allows rapid charging despite the presence of circuit components coupled serially with the cell.

[0018] Referring now to **FIG. 2**, illustrated therein is a preferred embodiment of a charger **200** in accordance with the invention. The charger **200** includes a microprocessor **202** having associated memory for storing cell identification data and charging methods. The microprocessor **202** acts as the "brain" of the charger **200**, as the microprocessor **202** is dominant over the other circuit components.

[0019] The charger **200** also includes power circuitry for delivering current from a power supply **211** to a battery. The power circuitry includes a power conversion regulator **204**. The power conversion regulator **204** converts voltage and current from levels produced by the power supply **211** to levels acceptable by the cells in the battery pack. For example, as power supplies **211** typically output voltages exceeding the voltage limits of a rechargeable cell, a preferred power conversion regulator **204** is a buck, or step-

down, regulator to step the voltage down to a level that will not compromise the reliability of the cells. The power conversion regulator **204** is controlled by a pulse width modulated (PWM) control **203** that is subservient to the microprocessor **202**. Through the power circuitry, current is delivered from a power supply input terminal **201**, through the power conversion regulator **204** to a charging output terminal **205** that is coupled to the cell in the battery pack (not shown in **FIG. 2**). (The return path is through the return terminal **207**.)

[**0020**] The charger **200** optionally provides a trickle charge circuit **208** to charge cells with voltages below the manufacturer's recommended limits. The trickle charge circuit **208** preferably includes a high impedance resistor **212** and blocking diode **213**. The trickle charge circuit **208** provides just enough current to the cell as to bring it up to an acceptable rapid charge level. Once the cell reaches this level, the microprocessor **202** causes current to begin flowing through the power conversion regulator **204**.

[**0021**] Referring now to **FIGS. 3 and 4**, illustrated therein are two preferred batteries to be used in accordance with the invention. Referring to **FIG. 3, a** conventional nickel based battery **300** is shown. As stated above, chargers of nickel based batteries typically terminate charge by sensing temperature across time. Temperature is sensed by way of a thermistor **302**. The thermistor is mechanically disposed in close proximity to the nickel cells **301**. The thermistor **302** couples to the charger by way of a thermistor terminal **304**. Overcurrent protection **303**, preferably a positive temperature coefficient (PTC) resistor, is also provided.

[**0022**] Referring again to **FIG. 2**, when the battery (**300** of **FIG. 4**) is coupled to the charger **200**, the charging terminal **205** is coupled to the cell (**301** of **FIG. 3**). The microprocessor **402** recognizes the cell voltage to be indicative of a battery coupled to the charger **200**.

[**0023**] Once the charger **200** recognizes that a battery is present, the charger **200** identifies nickel based cells by way of a pair of switches **209**,**210**. Switches **209**,**210** begin in their standby state, preferably with switch **209** open and switch **210** closed. With the thermistor terminal (**304** of **FIG. 3**) is coupled to the identification input **206**, the thermistor (**302** of **FIG. 3**) is pulled to ground. The microprocessor **202** then identifies this battery as a nickel based battery. The microprocessor **202** then closes switch **209** while opening switch **210**. If the battery (**300** of **FIG. 3**) is nickel based, a thermistor (**302** of **FIG. 3**) will have a non-negative resistance value. If the thermistor is present, pull-up resistor **215** will cause a voltage to be present at an analog to digital (A/D) converter input **214**. Provided the voltage is within a predetermined range associated with nickel batteries, the microprocessor **202** knows that the battery is a nickel-based battery. The microprocessor **202** then charges the battery accordingly.

[**0024**] Referring now to **FIG. 4**, illustrated therein is a lithium-based battery **400** in accordance with the invention. The lithium battery **300**, like the nickel battery, includes a third terminal **403** for identification. The third terminal **403**, however, is coupled directly to the lithium cell **401** by way of a high impedance resistor **404**. The high impedance resistor **404** has a resistance value that is sufficiently high to prevent charging current from bypassing the safety circuit **402** en route to the cell **401**.

[**0025**] Referring now again to **FIG. 2**, the charger **200** also identifies lithium based cells by way of switches **209**,**210**. When the third terminal (**403** of **FIG. 4**) is coupled to the identification input **206**, the microprocessor **202**, like with the nickel battery above, opens switch **209** while closing switch **210**. Since the battery (**400** of **FIG. 4**) is lithium based with the third terminal (**403** of **FIG. 4**) coupled to the cell (**401** of **FIG. 4**), a voltage is present at the high impedance A/D converter input **214**. Since this voltage is not ground (as would be the case with nickel batteries), the microprocessor **202** knows that the battery is a lithium-based battery. The microprocessor **202** opens switch **209**. This ensures that the cell voltage is represented at the high impedance A/D input. The microprocessor **202** then charges per the method illustrated in **FIG. 5**. Note that as the microprocessor **202** has access to both the voltage of the output terminal **205** and the cell voltage (by way of terminal **206**), the microprocessor **202** can determine the voltage drop across the lithium protection circuit (shown as **402** in **FIG. 4**), regardless of what components that circuit may comprise.

[**0026**] Referring now to **FIG. 5**, illustrated therein is a method of charging a lithium battery in accordance with the invention. The,method is employed by the microprocessor (**202** of **FIG. 2**) once the microprocessor determines that it is coupled to a lithium battery. All steps performed are conducted by the microprocessor, which then directs the other charger components.

[**0027**] The battery is first checked to ensure that it is below the maximum threshold as step **501**. For example, in a two-cell, serial combination, this may be 8.6 volts. If the cell is greater than this threshold, the charging current is terminated at step **502**.

[**0028**] The cell is then checked to ensure that it is above a minimum threshold at step **503**. Cell manufacturers generally recommend avoiding the application of a rapid charging current when the cell is below a threshold. For a single lithium cell, this voltage is generally around 2.3 volts. If the cell is below this threshold, a trickle current, preferably about 50 mA, is applied at step **504** in an attempt to slowly bring the cell to the minimum threshold voltage.

[**0029**] The microprocessor **202** then checks to see if this is the first time through the method at step **505**. If this is the first time through, the charger sets the current to the maximum rate at step **506**. The maximum rate is generally the capacity rate, which is on the order of 850 milliamps for a single cell (or a serial combination of single cells). If it is not the first time through, the charger holds the current constant.

[**0030**] The microprocessor **202** then checks to see if the elements (within the battery pack) coupled serially with the cell are saturated at step **507**. Recall from the discussion above that the microprocessor **202** has access to the cell voltage through terminal **206**, as well as to the power supply output at terminal **205**. As the serial elements in lithium battery packs generally comprise transistors, the microprocessor **202** knows that the voltage across such an element will be small when the element is fully conducting. However, if there is some sort of limiting event, e.g. the pass transistor has become too hot, the impedance of, and corresponding voltage across, the serial element will increase rapidly. Thus, the microprocessor **202**, at step **507**, checks to

see that the difference in voltage between terminal **205** and **206** is below a predetermined threshold. An exemplary value is 1.5 volts.

[**0031**] If the serial element is not saturated, then the microprocessor sets an event flag at step **508** and moves into the "manage off time" branch at point **509**. From this point, the microprocessor **202** first checks to see if the off time (which is the amount of time that the current has been reduced) is less than a predetermined threshold, for example 1 minute. During the first pass through the manage off time branch, this time will be less than the predetermined threshold because the current will still be set to the maximum rate by way of step **506**.

[**0032**] As the off time is less than the predetermined threshold, the microprocessor **202** reduces the current to a minimum value, like 20 milliamps for example. This reduction in current will allow whatever event caused the serial element to leave saturation to subside. For example, if the serial element was a transistor that was getting too hot, then the reduction in current will allow it to cool. The microprocessor **202** provides an adequate time for this to occur by ensuring that the off time timer is clear at step **512** and then initializing it to a predetermined time, say 1 minute, at step **513**.

[**0033**] Once the predetermined time has passed, as at step **514**, the microprocessor **202** then attempts to reapply the previous charging current at step **515**. As the event causing the serial element to move out of saturation may still be present, the microprocessor **202** only does this for a short time, say 1 second, as is noted at step **516**. After applying the charging current for this brief interval, the microprocessor **202** immediately checks the serial element again to see whether it is in saturation (step **517**). If it is, the microprocessor **202** presumes that the event causing the serial element to move out of saturation is gone. If it is not, however, the microprocessor **202** then decrements the current by a predetermined amount, for example 50 mA, at step **518** and repeats the process. Charging is finally terminated with the microprocessor **202** decrements current below a predetermined threshold, like 200 mA.

[**0034**] The method also predicts when the battery is nearly fully charged. Note that the "trip flag", indicative of an event occurring that sends the serial element out of saturation, is set at step **508**. When the current is decremented below the predetermined threshold, and the trip flag is set, the microprocessor **202** presumes this to correspond to a cell that is nearly fully charged, as the microprocessor **202** will have tried to restart the maximum current many times. Thus, when a predetermined current level is reached through microprocessor **202** decrementation, the microprocessor **202** will actuate an annunciator, like a LED for example, to indicate that the battery is nearly fully charged. By way of example, when a current level corresponding to 90% charge is reached, the microprocessor **202** may toggle an LED from red (indicating rapid charge) to flashing green (indicating approximately 90% full).

[**0035**] To recap by way of summary, the method charges a battery at a maximum current while sensing both the voltage at the battery terminal and at the cell. When an event occurs that causes the difference in voltage between the battery terminal and the cell to increase above a predetermined threshold, the method reduces the current to a minimum level for a predetermined time. After the predetermined time has elapsed, the method reinitiates maximum current. If the difference in voltage between the battery terminal and the cell remains small, then the method continues to charge at the high rate. If, however, the voltage between the battery terminal and the cell increase again, the method will decrement the charging current by a predetermined amount. The method repeats this process until the current has been decremented to a level indicative of full capacity.

[**0036**] To examine this graphically, please refer to **FIG. 6**. When the battery is inserted into the charger, the charger ramps the current up to the maximum charging current for the particular application. This is shown at segment **601**. When a "trip" event (where the voltage drop across serial elements increases), such as point **602**, the charger reduces the current to a minimum level at segment **603**. After a predetermined time represented by **607** passes, the current is then ramped up to a high level (at segment **604**) for a brief interval. If another trip event occurs (point **608**), then the charger decrements current by a predetermined amount at segment **605**. This charging current continues until another trip event occurs at point **606**. The process repeats until a current level indicative of full charge is reached.

[**0037**] While the preferred embodiments of the invention have been illustrated and described, it is clear that the invention is not so limited. Numerous modifications, changes, variations, substitutions, and equivalents will occur to those skilled in the art without departing from the spirit and scope of the present invention as defined by the following claims. For example, while thermal events have been discussed herein as exemplary ways that serial elements may be taken out of saturation, it will be clear to those of ordinary skill in the art that other events, including cells reaching a termination voltage, could also cause the impedance of serial elements to increase.

What is claimed is:

1. A method of charging a battery, the method comprising the steps of:

a. providing a battery having at least three terminals: a first terminal for receiving a charging current, a return terminal, and a third terminal coupled to a cathode of a rechargeable cell disposed within the battery;

b. applying a charging current having a first magnitude;

c. sensing a difference in voltage between the first terminal and the third terminal; and

d. reducing the charging current to a second magnitude when the difference in voltage between the first terminal and the third terminal exceeds a predetermined threshold.

2. The method of claim 1, further comprising the step of holding the charging current at the second magnitude for a first predetermined time.

3. The method of claim 2, further comprising the step of applying a charging current of the first magnitude for a second predetermined time after the first predetermined time has elapsed.

4. The method of claim 3, further comprising the step of decrementing the current by a predetermined amount if the

voltage between the first terminal and the third terminal exceeds the predetermined threshold during the second predetermined time.

5. The method of claim 4, further comprising the step of actuating an annunciator when the current has been decremented to a predetermined current level.

6. The method of claim 5, further comprising the step of terminating charging current when the voltage between the second and third terminals reaches a predetermined termination voltage.

7. The method of claim 6, further comprising the step of applying a minimum current when the voltage between the second and third terminals is below a predetermined minimum voltage.

* * * * *